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Original Article

Association between abductor muscle strength and functional outcomes in hip-fractured patients: a cross-sectional study

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Abstract

Objectives: To explore associations between abductor strength and functionality in hip-fracture patients. **Methods:** Ninety-six participants (70-84 years) followed a 12-week physiotherapy programme emphasizing hip abductor strengthening. The abductor's isometric strength, the hip strength asymmetry (HSA), expressing the ratio of abductor strength in the fractured versus the contralateral hip, and the patients' functional level were recorded 3 months post-intervention. Functionality was assessed using the Timed Up & Go (TUG) test and the Lower Extremity Functional Scale (LEFS-Greek). **Results:** Abductor isometric strength and HSA were correlated negatively with TUG test (Pearson's r: -0.881 and -0.810, respectively; $p<0.001$) and positively with LEFS-Greek (Spearman's ρ: 0.668 and 0.404, respectively; $p<0.001$). Of all independent variables examined, abductor isometric strength was the main predictor of functional capacity, being strongly and directly associated with a faster TUG test time ($p<0.001$) and a better LEFS-Greek score ($p<0.001$). Abductor's isometric strength and age explained 79.0% and 49.5%, whereas HSA and age explained 69.7% and 41.9% of TUG and LEFS-Greek variance, respectively. **Conclusions:** Abductor isometric strength was the main predictor of hip-fracture patients' functionality, strongly enhancing the measured functional outcomes. Hip abductor strengthening appears to be of major clinical importance and may contribute significantly to the functional rehabilitation of hip-fractured patients.

Keywords: Postoperative Physiotherapy Intervention, Hip Abductor Strength, Functionality, Timed Up & Go Test, Lower Extremity Functional Scale

Introduction

The incidence of fall-related hip fractures in elderly people is a major concern for national health care systems worldwide, being associated with excess mortality within the first year[1]. These patients often experience a severe reduction in functionality: 40-70% have deficiency in the performance of daily-life activities[2], 73% require assistance with their instrumental activities at home[3], 50% are not capable of ambulating independently[4,5], while only approximately 40% regain their pre-fracture level of independence[6]. Furthermore, hip fracture represents a key risk factor for new falls in these patients, including recurrent hip fractures[6].

According to the terminology of the Classification of Functioning, Disability and Health (ICF), functionality is a broad term that embraces the body's functions and structures while taking account of specific activities (performance of tasks) as well as social participation (involvement in real life situations)[7]. As functionality is the basis of the concept of health for the elderly, hip fracture-induced restrictions in the performance of daily-life activities can adversely affect a patient's quality of life[8].

The ultimate goal of hip-fracture management is to help patients maximise their functional recovery and return to

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the highest possible level of independence. There are well-designed physiotherapy interventions that aim to increase the strength of key muscle groups of the lower limb after hip fracture, so as to improve static and dynamic balance and enhance functionality[8-19]. There is increasing evidence that strategies focusing on increasing hip abduction strength are related to improvements in indicative functional parameters, such as lateral balance control, dynamic balance[17,19], independent gait[9] and self-reported mobility[9,18], and could potentially reduce the frequency of falls[20]. However, those studies did not attempt to model the relationship between hip abductor strength and functionality using specific statistical techniques, such as multivariable regression analysis. Such analysis could have been used to derive a more accurate prediction of the effects that hip abductor strength may have on the patient's functionality. In addition, an understanding of these issues could help towards more effective physiotherapy strategies to be implemented in the postoperative period, in order to improve long-term functional outcomes and hence the quality of life of elderly hip-fracture patients.

The purpose of the present study was to explore the possible relationships between hip abductor strength and patients' functional capacity after a 3-month physiotherapy programme. In addition, our aim was to quantify possible interrelations in a predictive model of strength-to-functional outcomes for hip-fractured patients. It was hypothesized that the isometric strength of abductors is related to the functional performance of hip-fractured patients.

Materials and methods

Study design and setting

This was a cross-sectional study involving hip-fractured patients who had completed a postoperative three-month physiotherapy intervention aimed at strengthening the abductor muscles (Appendix 1).

The study was conducted in accordance with the ethical principles stated in the Declaration of Helsinki and its amendments for medical research involving human subjects[21]. The General Assembly of Special Synthesis of the National and Kapodistrian University Medical School of Athens, Greece and the Scientific Research Council of the "KAT" General Hospital of Attica, Athens, Greece approved the protocol of the present study. The study conformed to the "Strengthening the Reporting of Observational studies in Epidemiology" (STROBE) statement for reporting cross-sectional studies[22].

All participants had undergone hip hemiarthroplasty through Hardinge's direct lateral approach. The physiotherapy intervention was initiated on the second postoperative day and lasted 12 weeks, the first week on an in-patient basis then home-based for the remaining 11 weeks. A modification of the rehabilitation protocol of Papathanasiou et al[23] was implemented in all cases (Appendix 1). The same physiotherapist carried out the physiotherapy intervention during hospitalization and at home, being responsible for the progress of the program and ensuring the patient's adherence to it. During hospitalization, individual sessions lasting approximately 30 minutes were performed on a daily basis. Following discharge, the rehabilitation programme continued at home, three times per week until the 12th postoperative week. The duration of the home sessions was initially 30 minutes and increased to a maximum of 50 minutes. If a patient cancelled a session for personal or medical reasons, the physiotherapist changed the appointment so that the patient would still complete three sessions per week.

Table 1. Measures of demographic/personal characteristics and clinical variables (n=96).

Characteristics - Variables	Values
Age (years)	77.53 ± 4.24 (70-84)
Height (cm)	166.82 ± 7.10 (155-188)
Weight (kg)	74.55 ± 9.22 (55-90)
Body mass index (kg/m^2)	26.73 ± 2.30 (21.30-29.80)
Sex: men/women [n (%)]	24 (25%) / 72 (75%)
Abductor isometric strength (N)[1]	73.44 (±15.57) (51,15-117)
Hip strength asymmetry(%)[2]	78.27±2.06 (69.8-81.9)
TUG test (s)[3]	17.60±3.64 (11.1-26.2)
LEFS-Greek total score[4]	32.67±7.08 (21.0-43.0)

All quantitative variables are presented as mean ± standard deviation (min-max).

[1] Isometric strength of the abductors of the fractured hip.

[2] Isometric strength of the abductors of the fractured hip over the contralateral hip, expressed as percentage.

[3] The Timed Up & Go test.

[4] The total score of the Greek version of the Lower Extremity Functional Scale.

To represent the strength of hip abductors, the isometric strength of the fractured hip and the hip strength asymmetry (HSA), expressing the ratio of abductor strength in the fractured versus the contralateral hip, were defined as "independent variables". Functional outcomes were set as the "dependent variables". The patients' functional capacity was assessed using the objective performance-based Timed Up & Go (TUG) test[24] and the Greek version of the self-reported Lower Extremity Functional Scale (LEFS-Greek)[25,26]. In order to optimize the practical application of the study's findings, age, sex and body mass index (BMI) were explored as possible covariates, as they may confound the relation between strength and functionality[27-30]. All measurements were made by the same examiner, who was not involved in any part of the rehabilitation program.

Participants

One hundred ten patients who sustained a fall-related hip fracture were recruited prior to surgery and invited to participate in the study. Patients were highly motivated to participate in the study for the following reasons: a) they were encouraged to participate by the operating surgeon; b) following discharge, the rehabilitation programme continued at the patient's home, making it easy to comply; and c) patients who participated in the study received the physiotherapy treatment free of charge – an important factor in view of the current financial crisis in Greece.

The study sample consisted of individuals aged 70 to 84 years, who declared themselves to be community dwellers on hospital admission. To be eligible, individuals also had to have a BMI between 19 kg/m^2 and 30 kg/m^2 and should not have undergone previous orthopaedic surgery on the fractured or the contralateral hip. The patients who fulfilled these inclusion criteria and followed a 3-month physiotherapy programme, whose aims included abductor strengthening, were included in the study. Upon acceptance, participants gave their written informed consent; their demographic and personal characteristics were then recorded (Table 1).

Independent variables (predictors)

Abductors' isometric strength

The strength of the abductor muscles of the fractured hip was quantified by measuring maximum voluntary isometric contraction using a handheld dynamometer (Dial Push-Pull Gauge, USA. ICC: 0.899 95%CI:0.764-0.959)[30]. For isometric strength measurement, with the patient supine, the dynamometer was mounted 2 cm above the lateral femoral condyle, with the device stabilized against a wall. The examined limb was in neutral position. The participants performed two voluntary isometric contractions, each for 2 to 3 s, with a resting interval of 1 minute. The higher value of the two voluntary isometric contractions, measured in Newtons, was recorded.

In order to calculate the HSA, the isometric strength of the contralateral limb abductors was also measured. An HSA of 100% indicate that the isometric strength of the abductors in the fractured hip equalled the abductor strength of the contralateral hip.

Dependent variables (functional outcomes)

Timed Up & Go test

The TUG test was used to assess participants' functionality. This test was introduced in 1991 as a modification of the "Get-Up and Go" test[24]. It is a simple, rapid, and widespread clinical tool for the measurement of the functionality and mobility of the lower limbs[32]. The TUG test measures the time (in seconds) taken by a participant to stand up from an armed chair with a seat height of 46 cm, walk for 3 m, turn around a cone and return to sit on the same chair. Participants were asked to perform the test as quickly as they could while still feeling safe, and were allowed to use the walking aid on which they depended at the time of measurement. The TUG test was performed so that the contralateral limb was closer to the cone at the turn[17]. The participants performed the test twice, with a 5-minute resting interval in between. The faster of the two performance times was recorded.

Lower extremity functional scale

Self-perceived functional ability was assessed using the LEFS[33], a functional status evaluation tool that aims to investigate the degree of difficulty an individual experiences in performing everyday tasks[33]. It has been shown to be a valid, reliable, and responsive measure of patients' functional limitations after hip arthroplasty[34] and after hip fracture[35]. The questionnaire has 20 items; each item is scored on a 5-point Likert scale from 0 to 4. Answers are summed and reported as a score (0-80), with higher scores reflecting greater self-perceived functional ability[33]. In the present study, the reliable[24] and valid[26] Greek version of the LEFS questionnaire (LEFS-Greek) was used.

Statistical analysis

Using a two-sided hypothesis test with a significance level of 0.05, it was estimated that a sample size of 96 participants would achieve 90% power to detect a difference of 0.28 between the null hypothesis correlation coefficient of 0.25 and the alternative hypothesis correlation coefficient of 0.53 between the variable "isometric strength of the fractured hip" and the TUG test performance time or the LEFS-Greek total score.

All quantitative variables (age, BMI, abductor isometric strength and HSA, TUG test performance time and LEFS-Greek total score) were expressed as mean ± standard deviation (SD), while categorical variables were represented as frequencies and percentages (%). The Kolmogorov–Smirnov test was used to examine the normal distribution of the quantitative variables. Bivariate analysis was performed to determine the relation between the selected variables before they were entered into the regression model. Pearson's correlation coefficient was used for the analysis of TUG test performance time, while Spearman's correlation coefficient was used to evaluate LEFS-Greek total score.

Multivariable regression analysis was used to investigate the cross-sectional association between hip abductor strength and functional capacity. The models included age, sex, BMI, abductor isometric strength and HSA as independent predictors, while TUG test performance time and LEFS-Greek total score were the dependent variables. The selected variables were included in a multiple linear regression model, using the enter method to determine the influence of independent predictors on dependent variables. The association between independent variables and outcome variables was evaluated in terms of the magnitude of the R^2 value. All assumptions of linear regression analysis (homoscedasticity, linearity, normality and independence of error terms, as well as multicollinearity of independent variables) were met.

All tests were two-sided, a *p*-value of <0.05 was used to denote statistical significance. All analyses were carried out using the statistical package SPSS v. 17.00 (Statistical Package for the Social Sciences, SPSS Inc., Chicago, Ill., USA).

Table 2. Bivariate correlations among the examined quantitative variables (n=96).

		TUG test	LEFS-Greek	Abductor isometric strength	Hip strength asymmetry	Age
LEFS-Greek	Correlation coefficient	**-0.766^{a*}**				
	p-value	*<0.001*				
Abductor isometric strength	Correlation coefficient	**-0.881^{b*}**	**0.668^{a*}**			
	p-value	*<0.001*	*<0.001*			
Hip strength asymmetry	Correlation coefficient	**-0.810^{b*}**	**0.404^{a*}**	**0.714^{b*}**		
	p-value	*<0.001*	*<0.001*	*<0.001*		
Age	Correlation coefficient	**0.201^{b*}**	**-0.384^{a*}**	-0.093^{b}	0.033^{b}	
	p-value	*0.050*	*<0.001*	*0.367*	*0.754*	
Body mass index	Correlation coefficient	0.092^{b}	-0.186^{a}	-0.071^{b}	-0.052^{b}	0.028^{b}
	p-value	*0.371*	*0.080*	*0.489*	*0.621*	*0.790*

** **Bold** indicates significant correlation.*
TUG test: the Timed Up & Go test.
LEFS-Greek: the total score of the Greek version of the Lower Extremity Functional Scale.
Abductor isometric strength: the isometric strength of the abductors of the fractured hip.
Hip strength asymmetry: the isometric strength of the abductors of the fractured hip versus the contralateral hip, expressed as percentage.
[a] *Spearman's ρ correlation coefficient.*
[b] *Pearson's r correlation coefficient.*

Results

Descriptive and outcome data

Data collection continued until the number of participants required by the power calculation had been reached. As a result, the study lasted from April 2012 until November 2015 overall. One hundred and ten hip-fractured patients were assessed for eligibility. Four patients declined to participate, six were excluded because within a short time after hospital discharge they would return to the island where they permanently resided, and four did not complete the 3-month physiotherapy intervention. Finally, the data from 96 participants (24 men and 72 women) were analysed. The mean age of participants was 77.53 years (70-84) and the mean value of their BMI was 26.73 kg/m^2 (21.30-29.80) (Table 1).

At the end of the 3rd postoperative month, the mean value of the isometric strength of the abductors of the fractured hip was 73.44 N (±15.57 N) and the HSA was 78.27% (±2.06%). As regards functional outcomes, the mean TUG test performance time was 17.60 s (±3.64 s) and the mean LEFS-Greek total score was 32.67 (±7.08) (Table 1).

Main results

Bivariate analysis showed a high negative correlation between the isometric strength of the abductors of the fractured limb and TUG test performance time, and between HSA and TUG test performance time (Pearson's correlation coefficients: -0.881 and -0.810, respectively; p<0.001). A moderate positive correlation with LEFS-Greek total score was found for abductor isometric strength of the fractured limb (Spearman's correlation coefficient: 0.668; p<0.001) and a low positive correlation for HSA (Spearman's correlation coefficient: 0.404; p<0.001) (Table 2). Correlations between confounding factors (age, BMI) and functional outcomes are also presented in Table 2.

Isometric strength of abductors of the fractured limb (n=96)

To examine the contribution of the isometric strength of the abductors of the fractured limb to functional outcomes, the data from 96 patients were analysed, with no violation of any assumptions of the linear regression model implemented.

In multivariable regression analysis using the enter method, all independent variables accounted for 79.7% of the variance in TUG test performance time [$R^2=0.797$; $F(4.91)=89.37$, $p<0.001$] and for 51.7% of the LEFS-Greek total score variance [$R^2=0.517$; $F(4.91)=24.32$, $p<0.001$]. The results showed that the isometric strength of the abductors of the fractured limb (Beta coefficient ± SE: -0.904±0.049; $p<0.001$; $R^2=0.776$) and age (Beta coefficient ± SE: 0.105±0.041; $p=0.012$; $R^2=0.014$)

Table 3. Multiple linear regression using the isometric strength of the abductors of the fractured limb as independent variable (n=96).

Dependent variable: Timed Up & Go Test				
	R^2	Beta coefficient	SE	*p*-value
Constant	---	24.47	3.94	<0.001
Abductor isometric strength	0.776	-0.904	0.049	<0.001
Age	0.014	0.105	0.041	0.012
Sex	0.006	-0.650	0.395	0.103
BMI	0.001	0.039	0.075	0.601
Dependent variable: Lower Extremity Functional Scale – Greek version total score				
	R^2	Beta coefficient	SE	*p*-value
Constant	---	59.85	11.83	<0.001
Abductor isometric strength	0.401	1.209	0.148	<0.001
Age	0.094	-0.516	0.122	<0.001
Sex	0.008	1.416	1.186	0.236
BMI	0.014	-0.360	0.225	0.114

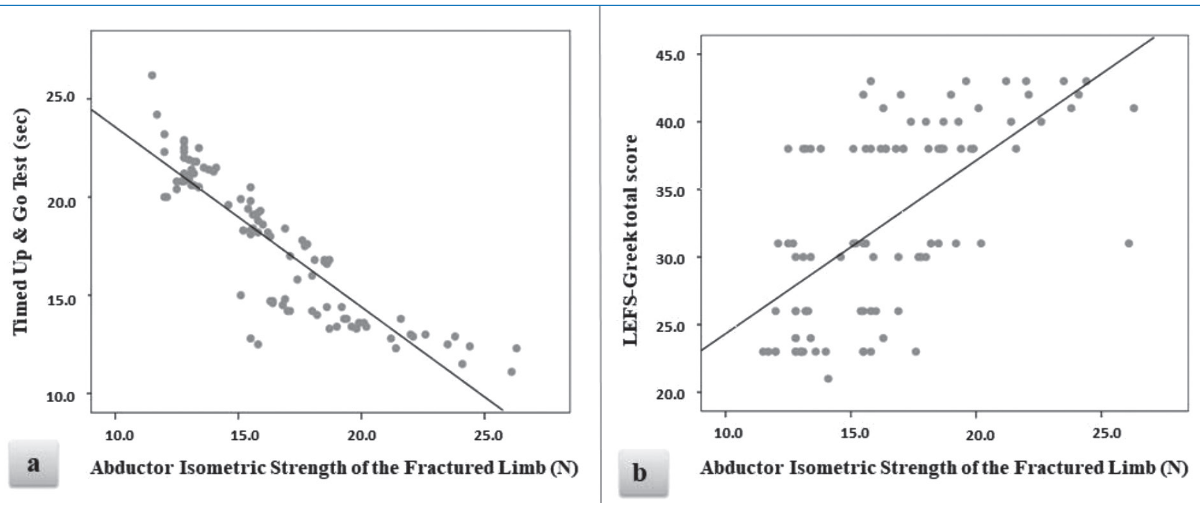


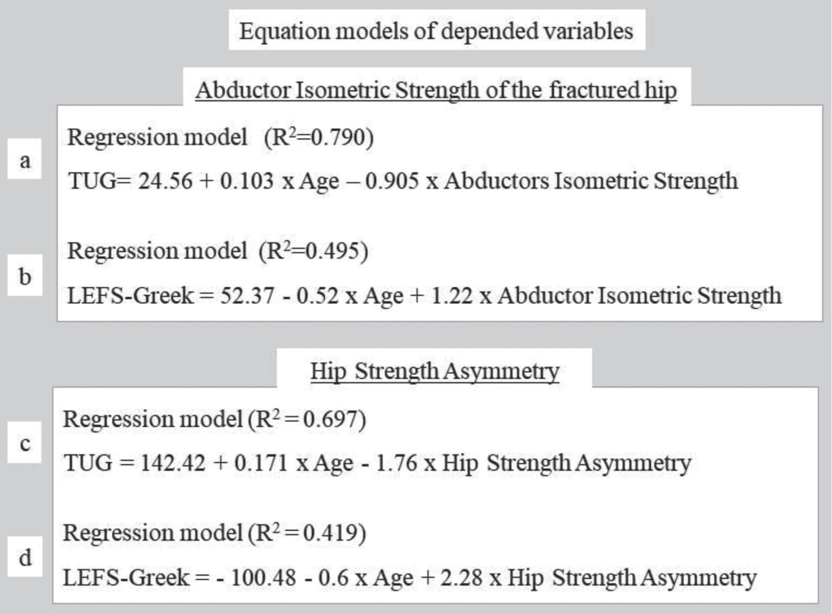
Figure 1. Scatter diagram between: a. abductor isometric strength of the fractured limb and TUG test performance time, b. abductor isometric strength of the fractured limb and LEFS-Greek total score.

accounted for 79.0% of the variance in TUG performance time, with abductor strength being the strongest significant predictor (Table 3, Figure 1a). Sex and BMI did not significantly influence the above dependent variables (Table 3). The final equation for the predictive model linking abductors' isometric strength of the fractured limb, age and TUG test performance time is shown in Figure 2a (R^2=0.790). Likewise, the isometric strength of the abductors of the fractured limb (Beta coefficient ± SE: 1.209±0.148; p<0.001; R^2=0.401) and age (Beta coefficient ± SE: -0.516±0.122; p<0.001; R^2=0.094) accounted for 49.5% of the variance in LEFS-Greek total score, with abductor strength again being the strongest significant predictor (Table 3, Figure1b). Sex and BMI did not significantly influence the above dependent variables (Table 3). The final equation for the predictive model linking abductors' isometric strength of the fractured limb, age and LEFS-Greek total score is presented in Figure 2b (R^2=0.495).

Hip strength asymmetry (n=93)

To examine the contribution of the HSA to functional outcomes, the data from 93 patients were analysed; three cases were excluded from the analysis as outliers.

Using the enter method, all independent variables accounted for 70.0% of the variance in TUG test performance time [R^2=0.700; F(4.88)=51.00, p<0.001]



Equation models of depended variables

Abductor Isometric Strength of the fractured hip

a

Regression model ($R^2=0.790$)

TUG= 24.56 + 0.103 x Age – 0.905 x Abductors Isometric Strength

b

Regression model ($R^2=0.495$)

LEFS-Greek = 52.37 - 0.52 x Age + 1.22 x Abductor Isometric Strength

Hip Strength Asymmetry

c

Regression model ($R^2 = 0.697$)

TUG = 142.42 + 0.171 x Age - 1.76 x Hip Strength Asymmetry

d

Regression model ($R^2 = 0.419$)

LEFS-Greek = - 100.48 - 0.6 x Age + 2.28 x Hip Strength Asymmetry

Figure 2. Regression equations of the dependent variables.

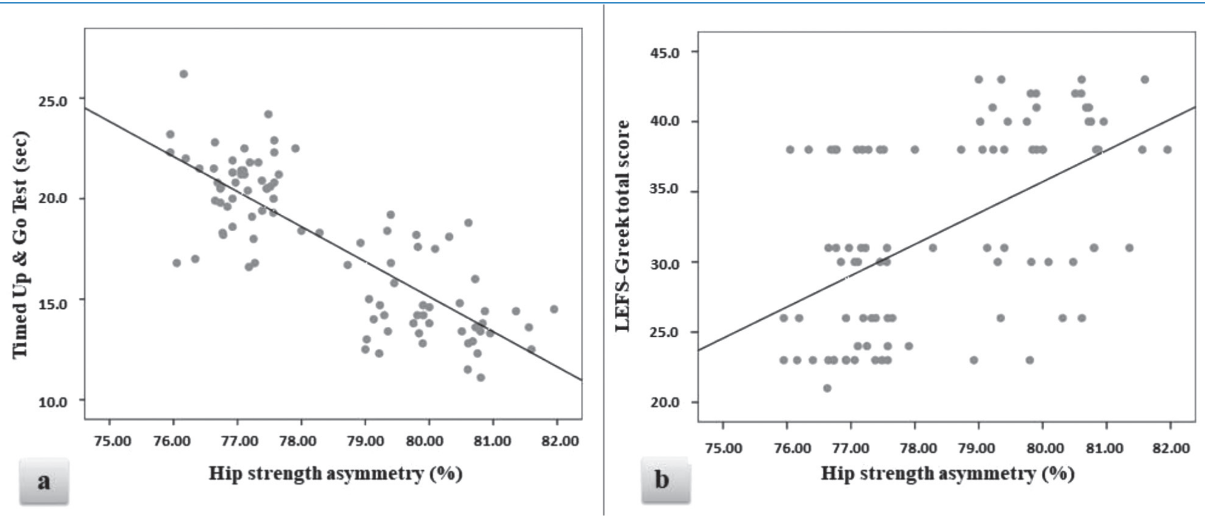


Figure 3. Scatter diagram between: a. hip strength asymmetry and TUG test performance time, b. hip strength asymmetry and LEFS-Greek total score.

and 42.9% of the LEFS-Greek total score variance [$R^2=0.429$; F(4.88)=16.51, p<0.001]. The results showed that HSA (Beta coefficient ± SE: -1.767±0.127; p<0.001; $R^2=0.656$) and age (Beta coefficient ± SE: 0.170±0.049; p=0.001; $R^2=0.041$) accounted for 69.7% of the variance in TUG performance time, with HSA being the strongest significant predictor (Table 4, Figure 3a). The final equation for the predictive model linking HSA, age and TUG test performance time is shown in Figure 2c ($R^2=0.697$). Similarly, HSA (Beta coefficient ± SE: 2.255±0.339; p<0.001; $R^2=0.287$) and age (Beta coefficient ± SE: 0.597±0.132; p<0.001; $R^2=0.132$) accounted for 41.9% of the variance in LEFS-Greek total score, with HSA again being the strongest significant predictor (Table 4, Figure 3b). Sex and BMI did not significantly influence the above dependent variables (Table 4).The final equation for the predictive model linking HSA, age and LEFS-Greek total score is presented in Figure 2d ($R^2=0.419$).

Table 4. Multiple linear regression using hip strength asymmetry* as independent variable (n=93).

Dependent variable: Timed Up & Go Test				
	R^2	Beta coefficient	SE	*p*-value
Constant	---	142.54	10.93	<0.001
Hip strength asymmetry*	0.656	-1.767	0.127	<0.001
Age	0.041	0.170	0.049	0.001
Sex	0.002	0.305	0.489	0.535
BMI	0.001	0.007	0.094	0.942
Dependent variable: Lower Extremity Functional Scale – Greek version total score				
	R^2	Beta coefficient	SE	*p*-value
Constant	---	-90.33	29.16	0.003
Hip strength asymmetry*	0.287	2.255	0.339	<0.001
Age	0.132	-0.597	0.132	<0.001
Sex	0.001	0.117	1.306	0.929
BMI	0.010	-0.306	0.250	0.224

** Isometric strength of the abductors of the fractured hip over the contralateral hip, expressed as percentage.*

Discussion

The present study examined the correlation between the strength of hip abductor muscles and the functional capacity of hip-fractured patients after a 3-month physiotherapy programme using multivariable regression analysis. The results showed that the isometric strength of the abductors of the fractured limb, the HSA and the age of the participants were – in descending order according to the magnitude of R^2 values – significant predictors that strongly influenced and enhanced the functional outcomes. All these independent variables had strong negative correlations with TUG test performance time, and moderately strong positive correlations with the self-reported LEFS-Greek total score; the combination of age with either isometric strength or HSA was able to predict a major proportion of the variance of TUG test performance time and a considerable proportion of LEFS-Greek total score. The isometric strength of the hip abductors of the fractured limb proved to be the most robust predictor of the functional outcomes measured, with age having only a small though significant contribution.

This study offers new insights into the progress of postoperative recovery in hip-fractured patients. The study's regression equations could be used in similar patient populations to predict their TUG test performance time or LEFS-Greek total score at the 3rd postoperative month, based on the isometric strength of their hip abductor muscles. In practical terms, this could be important for the early identification of hip-fracture patients who are at high risk of functional decline, so that appropriate strategies for acute-care rehabilitation may be implemented promptly.

To our knowledge, this is the first study to quantify the interrelations between hip abductor muscle strength and postoperative functional measures in a predictive model applicable to hip-fractured patients. Very few post-intervention studies have explored the relationships between lower limb muscle strength and various aspects of functionality, such as sit-to-stand[9], walking speed[11,16,19], stair-climbing speed[11,15], TUG test performance time[19], or self-reported functional ability[9,11,15], indicating that lower limb muscle strength is significantly associated with functional capacity. Nevertheless, all mentioned studies have focused on knee extensors[11,19], or on the overall strength of lower-extremity muscles[9,17,18], but not on hip abductor strength. The isometric strength of knee extensors has been found to be a significant predictor of TUG test performance time and functionality in hip-fractured patients[19]. However, as regards the results of our study, the isometric strength of hip abductors appeared to be a stronger predictor of functional capacity than that of knee extensors, explaining a wider variance of the TUG test performance time. The need for adequate lateral body stability and dynamic balance while a person is performing a TUG test may increase the importance of hip abductor muscle strength, since the abductors are a key muscle group related to gait and balance[17,19,20]. Thus, it seems that the isometric strength of hip abductors is a very strong indicator of functional ability and has considerable clinical impact.

In our study, participants with stronger hip abductor muscles completed the TUG test faster and, based on the LEFS-Greek total score, they had a greater capacity to carry out daily-life activities than those with weaker hip abductor muscles. It is broadly known that hip abductors, as frontal plane muscles, play an important role in bipedal stance and during gait[36]. These muscles are essential for controlling the head and the arms, stabilizing the trunk and hip during ambulation, controlling limb alignment, and transferring forces from the lower extremities to the pelvis[37]. They further allow a proper swing foot placement after the swing phase[38]. More specifically, there is a significant positive correlation between the strength and power of hip abductor muscles and the trunk-pelvis mediolateral balance control in the one-leg stance[18], the bipedal stance[39] and the independent gait[10]. Clinically, the aforementioned hip abductor muscle activations are fundamental to the performance of demand and/or ordinary functional activities[40]. On the other hand, an increasing interest in lateral control is emerging, given that impairments in this domain are thought to increase the risk of falls[20,41]. Recent findings of nonlinear gait analysis even suggest that gait stability in the frontal plane is of great interest for predicting fall risk[41,42]. Furthermore, it has been reported that lateral and posterolateral falls have greater potential for hip injury, including hip fractures, than falls in other directions[43-45]. In hip-fractured patients the insufficient strength and power of hip abductor muscles, which may already exist as a normal consequence of aging but are worsened by the trauma of surgery[46], usually result in serious limitations of dynamic balance[47]. Hence, these patients might not respond adequately to lateral perturbations that require postural responses of the hip or a stepping strategy to avoid falling[20,48]. Given the existing strong relationship between abductor strength and functionality, clinicians may consider a possible need for a more targeted and tailored physiotherapy intervention focused on hip abductor muscles, in order to improve rehabilitation strategies, to prevent mobility limitation, to optimize gains in physical function, to prevent future falls, second fractures, hospital readmissions and surgery, and finally to increase life expectancy.

It is worth noting that the correlation values between all independent variables and the TUG test performance time were higher than the respective values for the LEFS-Greek total score. This could be explained by the fact that TUG test is an objective performance-based assessment, while LEFS-Greek is a self-reported evaluation tool with an element of subjectivity. Moreover, it has been suggested that performance-based physical tests and patient-reported questionnaires measure different domains of functionality and disability[49].

The multiple linear regression model we used included sex and BMI as confounding factors, since they have been found to be related to muscle strength and functionality[50,51]. However, in our study sex did not significantly influence the interrelations between abductor strength and patients' functional level. In contrast, Cheng et al[50] have reported that muscle strength and functionality decrease earlier in female than in male patients. In addition, our results indicated that BMI did not influence the dependent variables we examined. This may be explained by the fact that the highest BMI value recorded was 29.80 kg/m^2; no obese patients participated in our study. In line with our findings, Ferrano et al[51] have shown in elderly people that a BMI≥30 kg/m^2 is associated with higher levels of lower-body disability.

The present study has both strengths and limitations. The design of the physiotherapy intervention, with initial in-hospital treatment followed by a continuing home-based exercise programme with the physiotherapist present, resulted in high compliance. The home-based programme afforded the opportunity to build a personal relationship between physiotherapist and patient, resulting in more effective individualization of treatment and better patient adherence. The homogeneity of the study's population, the adequate size of the sample, the thorough examination of all possible relationships between the selected independent variables, covariates, muscle strength and functional outcomes of hip-fractured patients added power to our results.

On the other hand, there are important limitations that have to be mentioned. Because of limited equipment availability, the measurement of hip abductor isometric strength was used as the main indicator of muscle capacity; thus, it was not possible to record other assessments of hip abductor strength, such as maximum torque, endurance, or total work. However, it has been reported that the measurement of isometric contraction is an objective indicator of muscle capacity and is able to detect alterations in muscle strength around the knee and hip region[52,53]. This form of muscle testing is often used in clinical practice and research to assess the progress and effectiveness of orthopaedic patients' rehabilitation[54]. In our study, the patients were invited to participate after their admission to the hospital for hip fracture surgery; hence, there was no way to measure abductor isometric strength in the fractured or contralateral hip prior to surgery or before the start of the physiotherapy intervention. The study's sample population consisted of community-dwelling individuals, who belong to the high-functioning band of hip-fracture patients. Therefore, it must be underlined that the observed pattern of association between hip abductor strength and functional outcomes could not be generalized to all hip-fractured patients. It would be interesting to investigate how well our predictive regression model performs in future studies involving hip-fracture patients with weaker or stronger hip abductor muscles, and different levels of independence, comorbidities or cognitive impairments. Additionally, in order to further investigate the association between hip abductor strength and functionality, the use of more independent variables or covariates, such as walking speed or quadriceps strength, should be included in the multivariable regression analysis.

In conclusion, the results of the present study show that hip abductor isometric strength was a main predictor of functional capacity, being strongly and directly associated with a faster TUG test performance time and a better LEFS-Greek total score. These findings highlight the importance of the integration of targeted exercise programs that focus on hip abductor strengthening in order to achieve optimal clinical outcomes, to promote recovery and maximize functional ability after a hip fracture.

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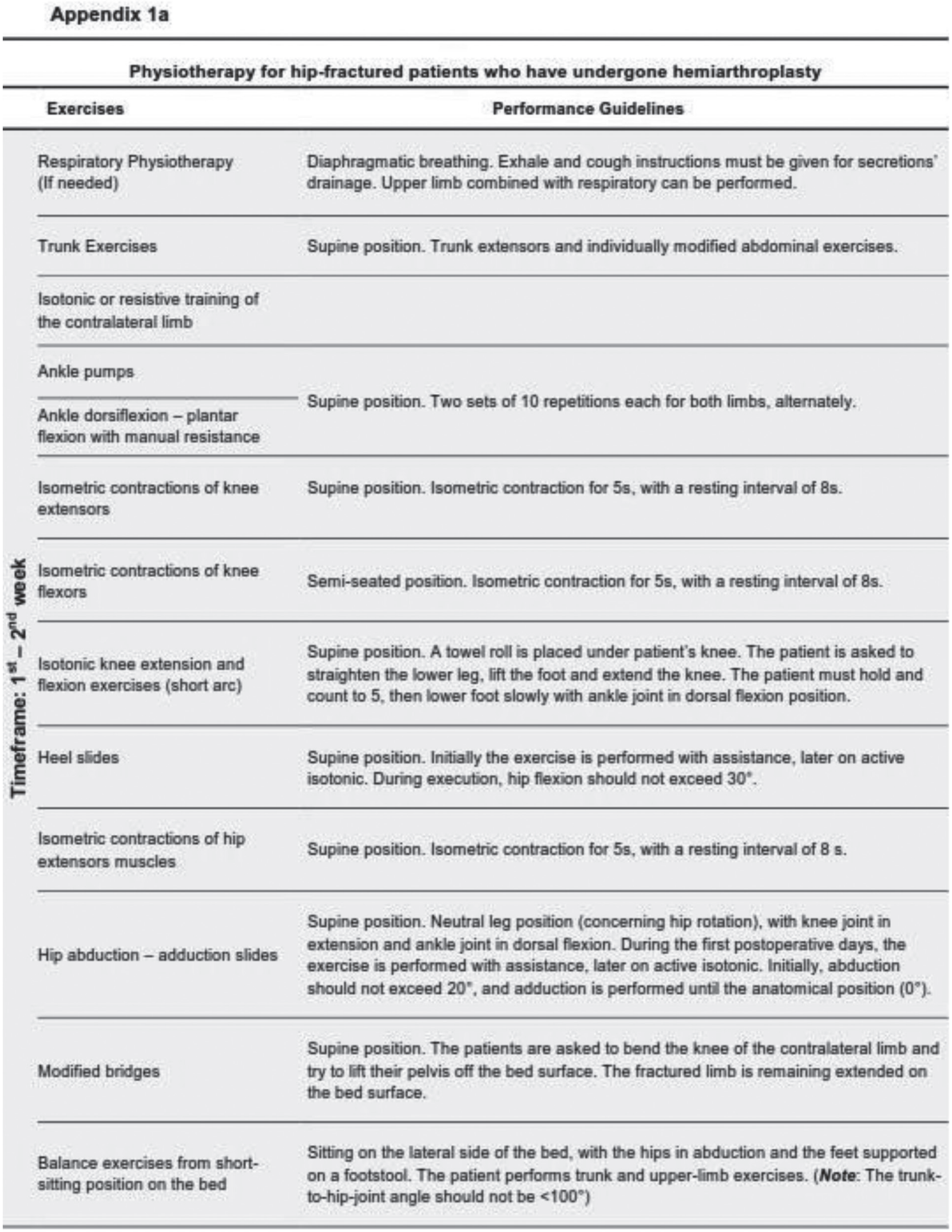
Authors' contribution

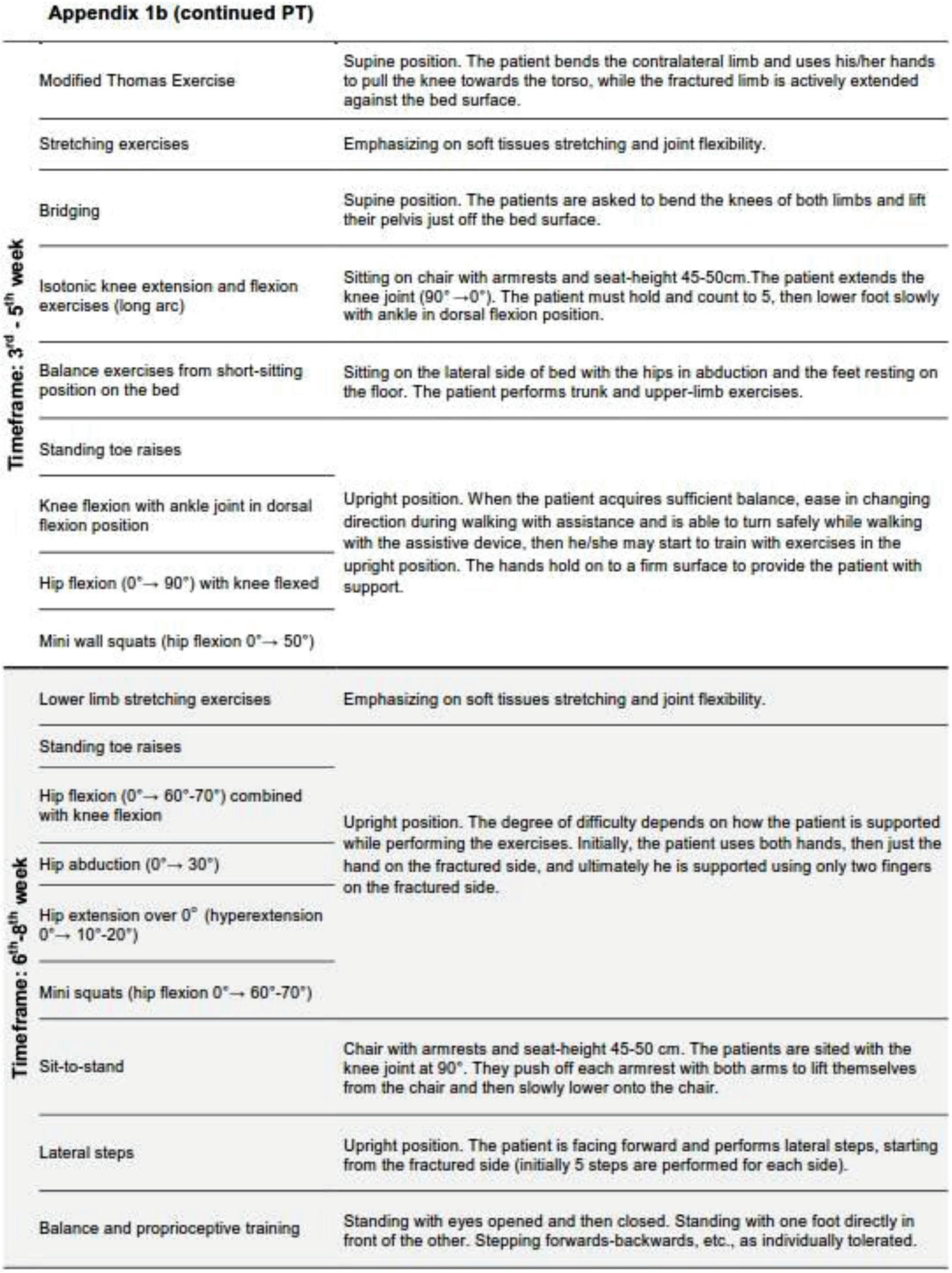
Study design: SS, GP and AG. Study conduct: SS, GP, IT, EC and NP. Data collection: SS and GP. Data analysis: SS and AG. Data interpretation: SS, GP, AG, IT, EC and NP. Drafting manuscript: SS, AG, and GP. Revising manuscript content: SS, GP, IT, EC and NP. Approving final version of manuscript: SS, GP, AG, IT, EC and NP. SS and AG take responsibility for the integrity of data analysis.



Appendix 1a

Physiotherapy for hip-fractured patients who have undergone hemiarthroplasty		
	Exercises	**Performance Guidelines**
Timeframe: 1st – 2nd week	Respiratory Physiotherapy (If needed)	Diaphragmatic breathing. Exhale and cough instructions must be given for secretions' drainage. Upper limb combined with respiratory can be performed.
	Trunk Exercises	Supine position. Trunk extensors and individually modified abdominal exercises.
	Isotonic or resistive training of the contralateral limb	
	Ankle pumps	Supine position. Two sets of 10 repetitions each for both limbs, alternately.
	Ankle dorsiflexion – plantar flexion with manual resistance	
	Isometric contractions of knee extensors	Supine position. Isometric contraction for 5s, with a resting interval of 8s.
	Isometric contractions of knee flexors	Semi-seated position. Isometric contraction for 5s, with a resting interval of 8s.
	Isotonic knee extension and flexion exercises (short arc)	Supine position. A towel roll is placed under patient's knee. The patient is asked to straighten the lower leg, lift the foot and extend the knee. The patient must hold and count to 5, then lower foot slowly with ankle joint in dorsal flexion position.
	Heel slides	Supine position. Initially the exercise is performed with assistance, later on active isotonic. During execution, hip flexion should not exceed 30°.
	Isometric contractions of hip extensors muscles	Supine position. Isometric contraction for 5s, with a resting interval of 8 s.
	Hip abduction – adduction slides	Supine position. Neutral leg position (concerning hip rotation), with knee joint in extension and ankle joint in dorsal flexion. During the first postoperative days, the exercise is performed with assistance, later on active isotonic. Initially, abduction should not exceed 20°, and adduction is performed until the anatomical position (0°).
	Modified bridges	Supine position. The patients are asked to bend the knee of the contralateral limb and try to lift their pelvis off the bed surface. The fractured limb is remaining extended on the bed surface.
	Balance exercises from short-sitting position on the bed	Sitting on the lateral side of the bed, with the hips in abduction and the feet supported on a footstool. The patient performs trunk and upper-limb exercises. (***Note***: The trunk-to-hip-joint angle should not be <100°)

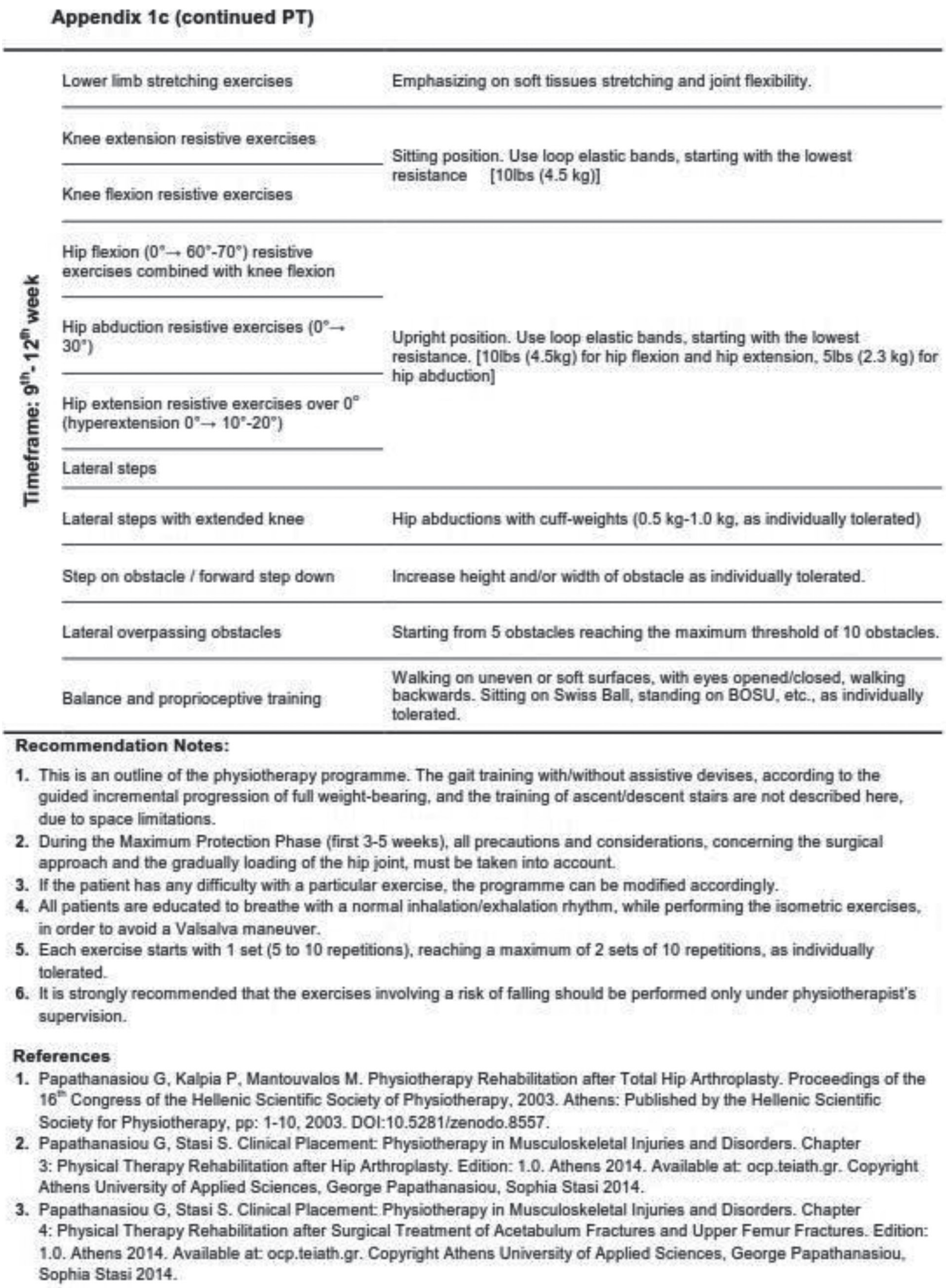
Figure 4. Appendix 1a: Physiotherapy for hip-fractured patients who have undergone hemiarthroplasty.



Appendix 1b (continued PT)

Timeframe: 3rd - 5th week	Modified Thomas Exercise	Supine position. The patient bends the contralateral limb and uses his/her hands to pull the knee towards the torso, while the fractured limb is actively extended against the bed surface.
	Stretching exercises	Emphasizing on soft tissues stretching and joint flexibility.
	Bridging	Supine position. The patients are asked to bend the knees of both limbs and lift their pelvis just off the bed surface.
	Isotonic knee extension and flexion exercises (long arc)	Sitting on chair with armrests and seat-height 45-50cm.The patient extends the knee joint (90° →0°). The patient must hold and count to 5, then lower foot slowly with ankle in dorsal flexion position.
	Balance exercises from short-sitting position on the bed	Sitting on the lateral side of bed with the hips in abduction and the feet resting on the floor. The patient performs trunk and upper-limb exercises.
	Standing toe raises	Upright position. When the patient acquires sufficient balance, ease in changing direction during walking with assistance and is able to turn safely while walking with the assistive device, then he/she may start to train with exercises in the upright position. The hands hold on to a firm surface to provide the patient with support.
	Knee flexion with ankle joint in dorsal flexion position	
	Hip flexion (0°→ 90°) with knee flexed	
	Mini wall squats (hip flexion 0°→ 50°)	
Timeframe: 6th-8th week	Lower limb stretching exercises	Emphasizing on soft tissues stretching and joint flexibility.
	Standing toe raises	Upright position. The degree of difficulty depends on how the patient is supported while performing the exercises. Initially, the patient uses both hands, then just the hand on the fractured side, and ultimately he is supported using only two fingers on the fractured side.
	Hip flexion (0°→ 60°-70°) combined with knee flexion	
	Hip abduction (0°→ 30°)	
	Hip extension over 0° (hyperextension 0°→ 10°-20°)	
	Mini squats (hip flexion 0°→ 60°-70°)	
	Sit-to-stand	Chair with armrests and seat-height 45-50 cm. The patients are sited with the knee joint at 90°. They push off each armrest with both arms to lift themselves from the chair and then slowly lower onto the chair.
	Lateral steps	Upright position. The patient is facing forward and performs lateral steps, starting from the fractured side (initially 5 steps are performed for each side).
	Balance and proprioceptive training	Standing with eyes opened and then closed. Standing with one foot directly in front of the other. Stepping forwards-backwards, etc., as individually tolerated.

Figure 5. Appendix 1b (continued PT).



Appendix 1c (continued PT)

Timeframe: 9th - 12th week	Lower limb stretching exercises	Emphasizing on soft tissues stretching and joint flexibility.
	Knee extension resistive exercises	Sitting position. Use loop elastic bands, starting with the lowest resistance [10lbs (4.5 kg)]
	Knee flexion resistive exercises	
	Hip flexion (0°→ 60°-70°) resistive exercises combined with knee flexion	Upright position. Use loop elastic bands, starting with the lowest resistance. [10lbs (4.5kg) for hip flexion and hip extension, 5lbs (2.3 kg) for hip abduction]
	Hip abduction resistive exercises (0°→ 30°)	
	Hip extension resistive exercises over 0° (hyperextension 0°→ 10°-20°)	
	Lateral steps	
	Lateral steps with extended knee	Hip abductions with cuff-weights (0.5 kg-1.0 kg, as individually tolerated)
	Step on obstacle / forward step down	Increase height and/or width of obstacle as individually tolerated.
	Lateral overpassing obstacles	Starting from 5 obstacles reaching the maximum threshold of 10 obstacles.
	Balance and proprioceptive training	Walking on uneven or soft surfaces, with eyes opened/closed, walking backwards. Sitting on Swiss Ball, standing on BOSU, etc., as individually tolerated.

Recommendation Notes:

1. This is an outline of the physiotherapy programme. The gait training with/without assistive devises, according to the guided incremental progression of full weight-bearing, and the training of ascent/descent stairs are not described here, due to space limitations.
2. During the Maximum Protection Phase (first 3-5 weeks), all precautions and considerations, concerning the surgical approach and the gradually loading of the hip joint, must be taken into account.
3. If the patient has any difficulty with a particular exercise, the programme can be modified accordingly.
4. All patients are educated to breathe with a normal inhalation/exhalation rhythm, while performing the isometric exercises, in order to avoid a Valsalva maneuver.
5. Each exercise starts with 1 set (5 to 10 repetitions), reaching a maximum of 2 sets of 10 repetitions, as individually tolerated.
6. It is strongly recommended that the exercises involving a risk of falling should be performed only under physiotherapist's supervision.

References

1. Papathanasiou G, Kalpia P, Mantouvalos M. Physiotherapy Rehabilitation after Total Hip Arthroplasty. Proceedings of the 16th Congress of the Hellenic Scientific Society of Physiotherapy, 2003. Athens: Published by the Hellenic Scientific Society for Physiotherapy, pp: 1-10, 2003. DOI:10.5281/zenodo.8557.
2. Papathanasiou G, Stasi S. Clinical Placement: Physiotherapy in Musculoskeletal Injuries and Disorders. Chapter 3: Physical Therapy Rehabilitation after Hip Arthroplasty. Edition: 1.0. Athens 2014. Available at: ocp.teiath.gr. Copyright Athens University of Applied Sciences, George Papathanasiou, Sophia Stasi 2014.
3. Papathanasiou G, Stasi S. Clinical Placement: Physiotherapy in Musculoskeletal Injuries and Disorders. Chapter 4: Physical Therapy Rehabilitation after Surgical Treatment of Acetabulum Fractures and Upper Femur Fractures. Edition: 1.0. Athens 2014. Available at: ocp.teiath.gr. Copyright Athens University of Applied Sciences, George Papathanasiou, Sophia Stasi 2014.

Figure 6. Appendix 1c (continued PT).

References

1. Abrahamsen B, van Staa T, Ariely R, Olson M, Cooper C. Excess mortality following hip fracture: a systematic epidemiological review. Osteoporos Int 2009;20:1633-50.
2. Beaupre LA, Jones CA, Saunders LD, Johnston DW, Buckingham J, Majumdar SR. Best practices for elderly hip fracture patients. A systematic overview of the evidence. J Gen Intern Med 2005;20(11):1019-25.
3. Osnes EK, Lofthus CM, Meyer HE, Falch JA, Nordsletten L, Cappelen I, et al. Consequences of hip fracture on activities of daily life and residential needs. Osteoporos Int 2004;15(7):567-74.
4. Boonen S, Autier P, Barette M, Vanderschueren D, Lips P, Haentjens P. Functional outcome and quality of life following hip fracture in elderly women: A prospective controlled study. Osteoporos Int 2004;15:87-94.
5. Van Balen R, Essink-Bot ML, Steyerberg E, Cools H, Habbema DF. Quality of life after hip fracture: a comparison of four health status measures in 208 patients. Disabil Rehabil 2003;25(10):507-519.
6. Cosman F, de Beur SJ, LeBoff MS, Lewiecki EM, Tanner B, Randall S, et al. Clinician's Guide to Prevention and Treatment of Osteoporosis. Osteoporos Int DOI 10.1007/s00198-014-2794-2.
7. World Health Organization (WHO): International Classification of Functioning, Disability and Health: ICF Geneva: WHO Library Cataloguing-in-Publication Data; 2001.
8. Beaupre LA, Binderb EF, Cameronc ID, Jonesa AC, Orwigd D, Sherringtone C, et al. Maximising functional recovery following hip fracture in frail seniors. Best Pract Res Clin Rheumatol 2013;27(6):771-788.
9. Briggs RA, Houck JR, Lastayo PC, Fritz MJ, Drummond MJ, Markus RL. High- intensity multimodal resistance training improves muscle function, symmetry during a sit-to-stand task, and physical function following hip fracture. J Nutr Health Aging 2018;22(3):431-438.
10. Barnes B, Dunovan K. Functional outcomes after hip fracture. Phys Ther 1987;67(11):1675-79.
11. Madsen OR, Lauridsen UB, Sorensen OH. Quadriceps strength in women with a previous hip fracture: relationships to physical ability and bone mass. Scand J Rehabil Med 2000;32:37-40.
12. Mitchell SL, Stott DJ, Martin BJ, Grant SJ. Randomized controlled trial of quadriceps training after proximal femoral fracture. Clin Rehabil 2001;15(3):282-90.
13. Hauer K, Specht N, Schuler M, Bärtsch P, Oster P. Intensive physical training in geriatric patients after severe falls and hip surgery. Age and Ageing 2002;31(1):49-57.
14. Binder EF, Brown M, Sinacore DR, Steger-May K, Yarasheski KE, Schechtman KB. Effects of extended outpatient rehabilitation after hip fracture. A randomized controlled trial. JAMA 2004;292(7):837-46.
15. Mangione KK, Craik RL, Lopopolo R, Tomlinson JD, Brenneman SK. Predictors of gait speed in patients after hip fracture. Physiother Can 2007;59:10-18.
16. Host HH, Sinacore DR, Bohnert KL, Steger-May K, Brown M, Binder EF. Training-induced strength and functional adaptations after hip fracture. Phys Ther 2007;87:292-303.
17. Mård M, Vaha J, Heinonen A, Portegijs E, Sakaru-Rantala R, Kallinen M, et al. The effects of muscle strength and power training on mobility among older hip fracture patients. Adv Physiother 2008;10:195-202.
18. Portegijs E, Sipila S, Rantanen T, Lamb SE. Leg extension power deficit and mobility limitation in women recovering from hip fracture. Am J Phys Med Rehabil 2008;87:363-370.
19. Shimada H, Kim H, Yoshida H, Yoshida Y, Saito K, Suzukawa M, et al. Factors associated with the Timed Up and Go test score in elderly women. J Phys Ther Sci 2010; 22:273-8.
20. Addison O, Inacio M, Bair W-N, Beamer BA, Ryan AS, Rogers MW. Role of Hip Abductor Muscle Composition and Torque in Protective Stepping for Lateral Balance Recovery in Older Adults. Arch Phys Med Rehabil 2016.
21. World Medical Association (WMA). Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects. 19th October 2013. © 2017 The World Medical Association, Inc. All Rights reserved. Available at: https//www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/
22. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet 2007;370:1453-7.
23. Papathanasiou G, Stasi S. Clinical Placement: Physiotherapy in Musculoskeletal Injuries and Disorders. Chapter 4: Physical Therapy Rehabilitation after Surgical Treatment of acetabulum fractures and upper femur fractures. Edition: 1.0. Athens 2014. Available at: ocp.teiath.gr. Copyright Athens University of Applied Sciences, George Papathanasiou, Sophia Stasi 2014 (written in Greek language).
24. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991;39:142-8.
25. Stasi S, Papathanasiou G, Anagnostou M, Galanos G, Chronopoulos E, Baltopoulos PI, Papaioannou NA. Lower Extremity Functional Scale (LEFS): Cross - cultural adaption into Greek and reliability properties of the instrument. Health Science Journal 2012;6(4):750-73.
26. Stasi S, Papathanasiou G, Korres N, Marinakis G, Chronopoulos E, Baltopoulos PI, Papaioannou NA. Validation of the Lower Extremity Functional Scale in community-dwelling elderly people (LEFS-Greek); determination of functional status cut-off points using TUG test. European Geriatric Medicine 2013; 4(4):237-41.
27. Doherty TJ. Invited review: aging and sarcopenia. J Appl

Physiol 2003;95:1717-27.

28. Manini TM, Visser M, Won-Park S, Patel KV, Strotmeyer ES, Chen H, et al. Knee extension strength cutpoints for maintaining mobility J Am Geriatr Soc 2007;55(3):451-7.
29. Zhu Y, Chen W, Sun T, Zhang Q, Cheng J, Zhang Y. Meta-analysis of risk factors for the second hip fracture (SHF) in elderly patients. Arch Gerontol Geriatr 2014;59(1):1-6.
30. Jankowski CM, Gozansky WS, Van Pelt RE, Schenkman ML, Wolfe P, Schwartz RS, et al. Relative contributions of adiposity and muscularity to physical function in community-dwelling older adults. Obesity (Silver Spring) 2008;16(5):1039-44.
31. Click Fenter P, Bellew JW, Pitts TA, Kay RE. Reliability of stabilised commercial dynamometers for measuring hip abduction strength: a pilot study. Br J Sports Med 2003;37:331-4.
32. Herman T, Giladi N, Hausdorff JM. Properties of the 'Timed Up and Go' test: more than meets the eye. Gerontology 2011;57:203-10.
33. Binkley JM, Stratford PW, Lott SA, Riddle DL. The lower extremity functional scale (LEFS): scale development, measurement properties, and clinical application. Phys Ther 1999;79(4):371-82.
34. Kennedy DM, Stratford PW, Robarts S, Gollish JD. Using outcome measure results to facilitate clinical decisions the first year after total hip arthroplasty. J Ortho Sports Phys Ther 2011;41:232-40.
35. Yeung TSM, Wessel J, Stratford PW, Macdermid J. Reliability, validity, and responsiveness of the Lower Extremity Functional Scale for inpatients of an orthopaedic rehabilitation ward. J Orthop Sports Phys Ther 2009;39:468-77.
36. Perry J. Gait Analysis: Normal and pathological function, 1st edition. USA: Slack Incorporated; 1992.
37. Lyons K, Perry J, Gronley JK, Barnes L, Antonelli D. Timing and relative intensity of hip extensor and abductor muscle action during level and stair ambulation: an EMG study. Phys Ther 1983;63:1597-605.
38. Vellas BJ, Rubenstein LZ, Ousset PJ, Faisant C, Kostek V, Nourhashemi F, et al. One-leg standing balance and functional status in a population of 512 community-living elderly persons. Aging (Milano) 1997;9(1-2):95-8.
39. Arvin M, van Dieën JH, Faber GS, Pijnappels M, Hoozemans MJM, Verschueren SMP. The role of hip abductor proprioception in mediolateral balance control of gait in older adults. Clinical Biomechanics 2016; 37:27-33.
40. Neumann DA. Kinesiology of the Hip: A Focus on Muscular Actions. JOSPT 2010;40:82-94.
41. Gafner S, Bastiaenens CHG, Terrier P, Punt I, Ferrari S, Gabriel Golda G, et al. Evaluation of hip abductor and adductor strength in the elderly: a reliability study. Eur Rev Aging Phys Act 2017;14:5.
42. Terrier P, Reynard F. Effect of age on the variability and stability of gait: a cross-sectional treadmill study in healthy individuals between 20 and 69 years of age. Gait Posture 2015;41:170-4.
43. Hayes WC, Myers ER, Morris JN, Gerhart TN, Yett HS, Lipsitz LA. Impact near the hip dominates fracture risk in elderly nursing home reside nts who fall. Calcif Tissue Int 1993;52:192-8.
44. Greenspan SL, Myers ER, Kiel DP, Parker RA, Hayes WC, Resnick NM. Fall direction, bone mineral density, and function: risk factors for hip fracture in frail nursing home elderly. Am J Med 1998;104:539-45.
45. Nankaku M, Kanzaki H, Tsuboyama T, Nakamura T. Evaluation of hip fracture risk in relation to fail direction. Osteoporos Int 2005;16:1315-20.
46. Winther SB, Husby VS, Foss OA, Wik TS, Svenningsen S, et al. Muscular strength after total hip arthroplasty: A prospective comparison of 3 surgical approaches. Acta Orthopaedica 2016;87:22-8.
47. Bertoti DB, Carcia CR. Pelvis and Hip. In: Houglum PA, Bertoti DB, editors. Brunnstrom's Clinical Kinesiology, 6th edition. Philadelphia: F.A. Davis Company; 2012. p. 413.
48. Horak FB, Henry SM, Shumway-Cook A. Postural perturbations: new insights for treatment of balance disorders. Phys Ther 1997;77:517–33.
49. Stratford PW, Kennedy DM. Performance measures were necessary to obtain a complete picture of osteoarthritic patients. J Clin Epidemiol 2006;59:160-7.
50. Cheng S-J, Yang Y-R, Cheng F-Y, Chen I-H, Wang R-Y. The changes of muscle strength and functional activities during aging in male and female populations. Int J Gerontol 2014;8:197-202.
51. Ferrano KF, Su YP, Gretebeck RJ, Black DR, Badylak SF. Body mass index and disability in adulthood, a 20 - year panel study. Am J Public Health 2002;92:834-40.
52. Brunner LC, Eshilian-Oates L, Kuo TY. Hip fractures in adults. Am Fam Phys 2003;67:537-42.
53. Martin HJ, Yule V, Syddall HE, Dennison EM, Cooper C, Aihie SA. Is hand-held dynamometry useful for the measurement of quadriceps strength in older people? A comparison with the gold standard Bodex dynamometry. Gerontology 2006;52:154-9.
54. Thorborg K, Serner A, Petersen J, Moller Madsen T, Magnusson P, Holmich P. Hip adduction and abduction strength profiles in elite soccer players implications for clinical evaluation of hip adductor muscle recovery after injury. Am J Sports Med 2011;39:121-6.